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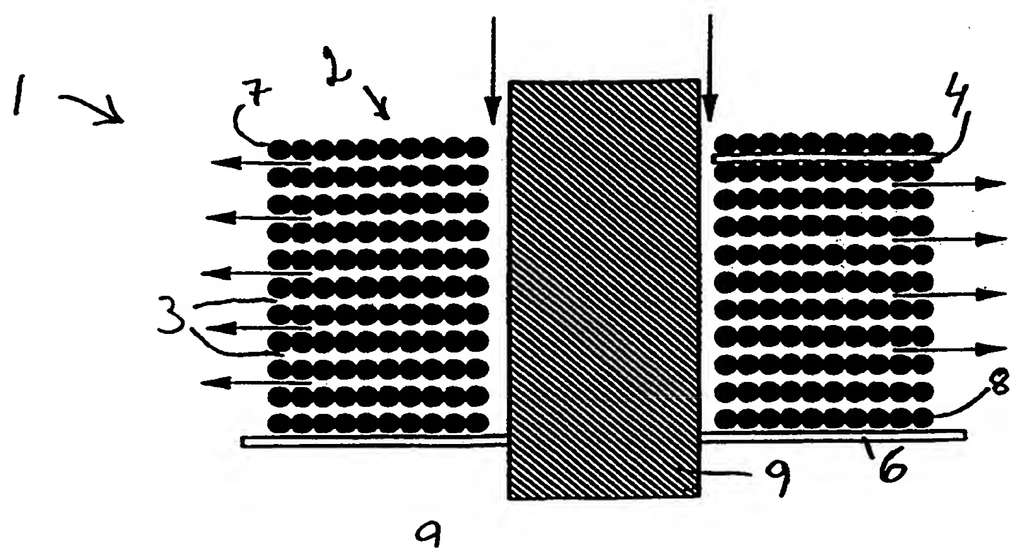
(54) Title: COMBINED AXIAL AIR-COOLING OF A TRANSFORMER



(57) Abstract

A power transformer (1) provided with a transformer core, whereby the core is wound with a high voltage cable (111) which is flexible and composed of an lectrically conducting core surrounded by an inner semiconducting layer (113), an insulating layer (114) of solid material surrounding the inner semiconducting layer (113), and an outer semiconducting layer (115) surrounding the insulating layer (114), said layers (113, 114, 115) being adhered to each other and that the winding (2) is provided with spacers (4) which are arranged to separate each cable turn in the axial directi n in order to create disk formed cooling ducts (3).

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Combined axial air-cooling of a transformer.

Technical field

The present invention relates to an air-cooled conductor wound power transformer and a procedure for air-cooling a conductor wound power transformer.

Background art

Today's power transformers are normally oil cooled. The transformers are provided with a core consisting of a number of core legs connected by yokes and windings constituting coils (primary, secondary, regulated) which are immersed in a sealed tank filled with oil. The heat, generated in the coils and core, is removed by oil circulating internally through the coil and core and released into the surrounding air via the walls of the vessel. Oil circulation may either be forced by pumping the oil around or it may be natural due to temperature differences in the oil. The circulating oil is cooled externally by air- or water cooling devices. External air-cooling of oil may be forced and/or effected through natural convection. The oil has an insulating function besides its role as conveyer of heat in oil cooled transformers for high voltage.

Dry transformers are normally air-cooled. They are normally cooled by natural convection as today's dry transformers are used at low power loading. The present technology related to axial cooling ducts, produced by means of a corrugated winding, is disclosed in GB 1.147.049, axial ducts for the cooling of windings embedded in cast resin is disclosed in EP 83107410.9 or the use of cross flow fans at peak load is disclosed in SE 7303919-0.

The need for cooling is greater for a power transformer. Forced convection is necessary to meet the cooling requirements of all windings. Natural convection is

not sufficient for cooling the conductor windings. It is important that the heat is transported by short means to the cooling agent and that this is conducted in an effective manner to the cooling agent. It is also important that all windings are in direct contact with a sufficient quantity of cooling agent.

A conductor is known through US 5 036 165, in which the insulation is provided with an inner and an outer layer of semiconducting pyrolized glassfiber. It is also known to provide conductors in a dynamo-electric machine with such an insulation, as described in US 5 066 881 for instance, where a semiconducting pyrolized glassfiber layer is in contact with the two parallel rods forming the conductor, and the insulation in the stator slots is surrounded by an outer layer of semiconducting pyrolized glassfiber. The pyrolized glassfiber material is described as suitable since it retains its resistivity even after the impregnation treatment.

Object of the invention

The object of the invention is to achieve an arrangement, as stated by way of introduction in the above-mentioned, which enables the air-cooling of a cable wound power transformer.

A further object of the invention is to provide radial cooling ducts between each layer of cables in which the cooling means is correctly distributed in order to meet the cooling requirements of the cable layers. Cooling of the core and winding is obtained by cooling air flowing axially along the leg of the core whereby an endplate steers the air radially out through horizontal ducts in the winding. The air is distributed in the ducts according to their cooling requirements by varying the height of the horizontal ducts.

Disk formed radial ducts are created by spacers which are inserted in the winding during winding of the coil. The cooling flow is produced by means of fans and the spacers are dimensioned such to produce flow in the ducts which meet the individual cooling requirements of the windings.

Summary of the invention

The present invention relates to a power transformer comprising a transformer core which is cable wound, arranged such that the winding is provided with spacers separating each cable turn in the axial direction in order to create disk formed ducts.

A first embodiment of the invention comprises hereby radial cooling ducts between each layer of the cable, i.e. each winding turn in the axial direction created by spacers during winding of the coil. This first embodiment comprises also fans in order to transport air through the ducts. The spacers are dimensioned such to produce different pressure resistance and thereby distribute the cooling flow such that the cooling requirements are met for each layer of the cable.

In a power transformer according to the invention the windings are composed of cables having solid, extruded insulation, of a type now used for power distribution, such as XLPE-cables or cables with EPR-insulation. Such a cable comprises an inner conductor composed of one or more strand parts, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding this and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the device according to the invention is based primarily on winding systems in which the winding is formed from cable which is bent during assembly. The flexibility of a XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable

30 mm in diameter, and a radius of curvature of approximately 65 cm for a cable 80 mm in diameter. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

Windings in the present invention are constructed to retain their properties even when they are bent and when they are subjected to thermal stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In a XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity within the range of 10^{-1} - 10^{6} ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating lay may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene (PMP), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber, butyl graft polyethylene, ethylene-butyl-acrylate-copolymers and ethylene-ethyl-acrylate copolymers may also constitute suitable polymers for the semiconducting layers. Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of E<500 MPa, preferably <200 MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks or other damage appear and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently large to contain the electrical field in the

cable, but sufficiently small not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and these layers will substantially enclose the electrical field between them. There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

Brief description of the drawings

The invention will now be described in more detail with particular reference to the accompanying drawings in which:

Figure 1 shows an axial view through a coil showing radial ducts between the cable layers in a first embodiment according to the invention;

Figure 2 shows the embodiment in Figure 1 as a top view having horizontal radial ducts formed by radial spacers;

Figure 3 shows schematically a radial view through the embodiment according to Figure 1 having a fan arrangement according to the invention;

Figure 4 shows a view through a high voltage cable according to the invention.

Description of the invention

Figure 1 shows in an axial view a part of a three phase power transformer 1 provided with windings 2, so called disk windings, constituting coils having cooling ducts 3 in the form of disks which are achieved by placing spacers 4 to

radially extend between each winding turn which is arranged axially. The winding is furthermore sealed off against a lower end plate 6. The winding coil may also be sealed off against the upper end of an upper winding disk 7 and against the lower end of a lower winding disk 8. The Figure shows furthermore a part of an iron core of the transformer, the part constituting its leg 9. In the case of the lower winding disk 8 acting as an axial sealant, the end plate 6 is used as a sealing means between the leg 9 of the core and the lower winding disk 8.

The principle concerning the cooling of windings of this embodiment is that air is forced axially along the iron core and thereafter distributed radially among the horizontal disk formed cooling ducts 3 formed by radial spacers 4 since the lower end of the winding coil is sealed off in order to force the air flow radially out through the windings. The spacers 4 are placed around a hypothetical circular cross-section between two winding turns. The spacers are inserted during winding of the coil. It is furthermore required in this embodiment that a fan be mounted for each coil. The air may hereby be sucked or forced through the coil.

Figure 2 shows a top view of the invention whereby the windings 2 are provided with spacers 4 placed radially in the form of a spoke, forming radial cooling ducts 14 in the form of a cake. In the shown embodiment the spacers 4 are arranged by dividing eight radial spacers 4 to each disk formed cooling duct 3. One disk formed cooling duct 3 consists thus of eight radial cooling ducts 14 in the form of a cake. All the disk formed cooling ducts 3 are connected to an axial cooling duct 15 formed around the periphery of the leg 9. The spacers 4 are furthermore radially extended. The form of and the material of the spacers is of less importance from a cooling point of view. The mechanical, magnetic and electrical aspects determine the shape, amount and material of the spacers. Air is supplied, as indicated previously, axially around the core.

Figure 3 shows an arrangement of a fan 10 connected to the inner axial cooling duct 15. The fan is connected by means of a fan hood 16 which is positioned against the inner side of an upper end plate 20 or against the upper winding disk 7 in a contact ring 17. The axial cooling duct 15 constitutes a space between the leg 9 of the core and the upper winding disk 7. By forcing air through the windings it is transported first through the axial cooling duct 15 and is then pressed out through the disk formed cooling ducts 3. When the air is sucked through the system it is sucked through the disk formed cooling ducts 3 to be accumulated thereafter and be transported out through the axial cooling ducts 15 and through the fans 10. The transformer in the embodiment shown in Figure 3 is further provided with a base plate 18 on which the windings rest, which base plate 18 acts as a sealing means against the leg 9 of the core at the end of the coil in such a way that the air is forced to be distributed in the disk formed cooling ducts 3. The coil of the transformer is also limited by the upper end plate 20 which seals off the axial air flow.

The cooling ducts have different cooling requirements and are therefore dimensioned differently to produce different pressure resistance and thereby distribute the cooling flow correctly.

Figure 4 shows a view in cross section of a high voltage cable 111 to be used as a transformer winding according to the present invention. The high voltage cable 111 comprises a plurality of strands 112 with circular cross-section of for example copper (Cu). These strands 112 are arranged in the centre of the high voltage cable 111. Around the strands 112 there is arranged a first semiconducting layer 113. Around the first semicinducting layer 113 there is arranged an insulating layer 114, of for example XLPE-insulation. Around the insulating layer 114 there is arranged

a second semiconducting layer 115. The concept of a high voltage cable in the present application does not comprise the outer shielding screen that normally surrounds such a cable for power distribution. The high voltage cable has a diameter in the interval 20 - 250 mm and a conductor area in the interval of 40 - 3000 mm^2.

The invention is not limited to the shown examples because several variations are possible within the framework of the invention. A fan is therefore not required for each coil. An arrangement with a fan which provides all three coils with the necessary amount of air is also feasible. The air may be either sucked or forced through the coil in order to achieve the desired cooling. Likewise spacers are subject to variation for neither their shape nor their numbers need be determined in order to obtain the right cooling. The spacers described in the first embodiment need not entirely cover the winding radially but may be placed in several ways. They need not either, as described in the second embodiment, be extended in the entire radial direction for this may be achieved in several other ways.

Another modification is to arrange a variable-speed control of the fans with the aid of temperature detectors in order to enable a variable cooling requirement depending on the load of the transformer.

A mantle casing may also be arranged in several other ways to the above-mentioned embodiments. The upper and the lower winding disk may be used as an outer casing which acts as a seal and the outside may be cooled by natural convection whereas the upper winding parts are cooled by air flowing radially.

CLAIMS

1. A power transformer (1) provided with a transformer core, characterized in that the core is wound with a high voltage cable (111) which is flexible and composed of an electrically conducting core surrounded by an inner semiconducting layer (113), an insulating layer (114) of solid material surrounding the inner semiconducting layer (113), and an outer semiconducting layer (115) surrounding the insulating layer (114), said layers (113,114,115) being adhered to each other and that the winding (2) is provided with spacers (4) which are arranged to separate each cable turn in the axial direction in order to create disk formed cooling ducts (3).

2. A power transformer according to claim 1, characterized in that the spacers (4, 12) are arranged radially between each winding turn.

3. A power transformer according to claim 2, characterized in that at least six spacers (4) are distributed evenly around a leg (9) of the transformer.

4. A power transformer according to any one of claims 2-3, characterized in that an end structure (6, 18) which acts as a seal against air flow is arranged around the leg (9) of the transformer.

5. A power transformer according to claim 4, characterized in that the upper end of a coil of the transformer is constituted by an upper end plate (20) which acts as a seal against axial air flow.

6. A power transformer according to any one of claims 2-3, characterized in that an upper winding disk (7) and a lower winding disk (8) together with the end structure (6, 18) constitute means to act axially as a seal.

7. A power transformer according to any one of claims 4-6, characterized in that a fan hood (16) provided with a fan (10) is arranged to either force or suck air through all the winding turns parallel with the leg (9) of the transformer.

8. A power transformer according to claim 7, characterized in that the fan hood (16) at the one end acts as a seal against either the upper winding disk (7) or the upper end plate (20).

9. A power transformer as claimed in any of claims 1-8, characterized in that said layers (113,114,115) are of materials having such elasticity and such coefficient of thermal expansion that the changes in volume in the layers (113,114,115) caused by temperature fluctuations during operation are absorbed by the elasticity of the material, the layers (113,114,115) thus retaining their adhesion to each other upon the temperature fluctuations that occur during operation.

10. A power transformer as claimed in any of claims 1-9, characterized in that the material in said layers (113,114,115) has high elasticity, preferably with a modulus of elasticity less than 500 MPa, preferably less than 200 MPa.

11. A power transformer as claimed in any of claims 1-10, characterized in that the coefficients of thermal expansion for the materials in said layers (113,114,115) are substantially the same.

12. A power transformer as claimed in any of claims 1-11, characterized in that the adhesion between layers (113,114,115) is of at least the same magnitude as in the weakest of the materials.

13. A power transformer as claimed in any of claims 1-12, characterized in that each of the semiconducting layers (113,115) essentially constitutes one equipotential surface.

14. A method for air cooling a cable wound power transformer according to any of the claims 1-13, characterized in that at least one fan (10) either forces or sucks air along the outside of the leg (9) of the transformer and radially or axially between each winding turn.

15. A method according to claim 14, characterized in that the spacers (4, 12) are inserted between the winding turns during the winding procedure of the transformer.

16. A method according to claim 15, characterized in that temperature detectors regulate the speed of the fans so that there is a suitable air flow.

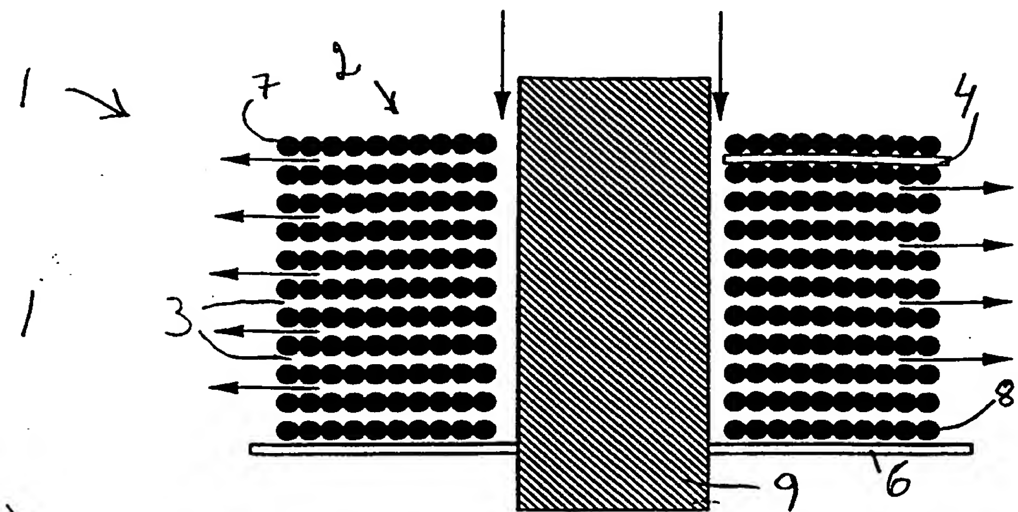

Fig. 1

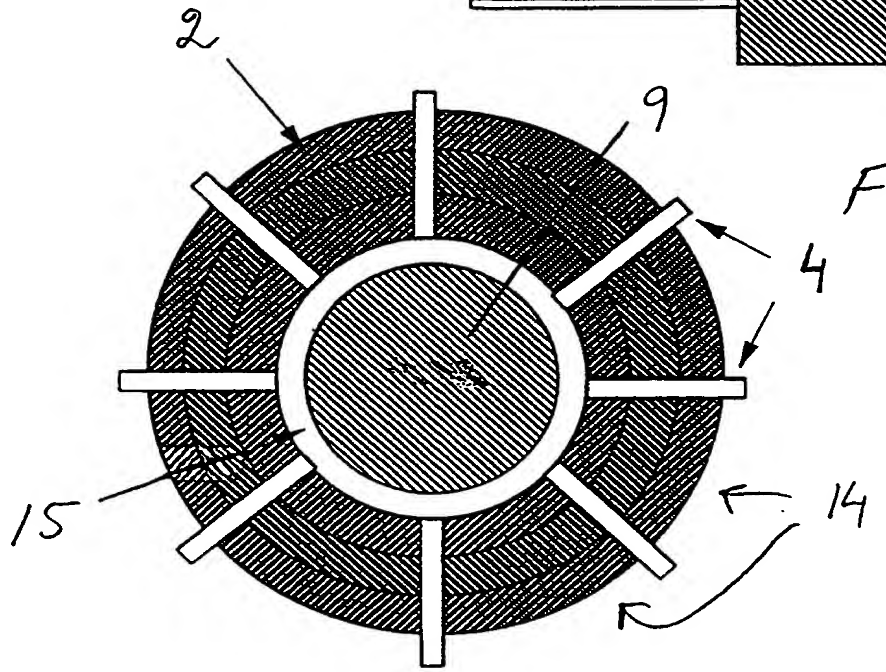

Fig. 2

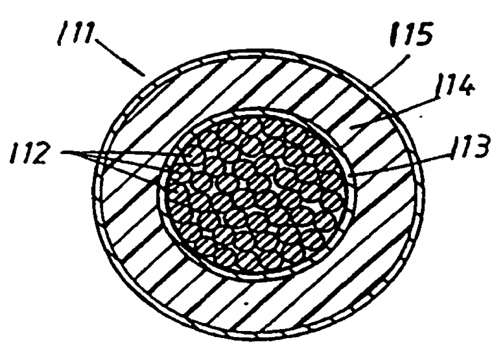

Fig. 4

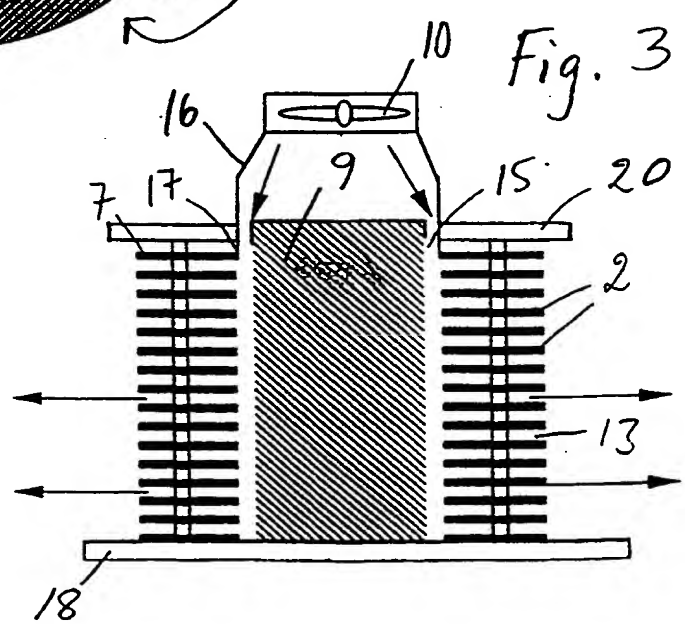

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/00161

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H01F 27/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 1304451 A (L.H. BURNHAM), 20 May 1919 (20.05.19), page 1, line 101 - line 106; page 2, line 114 - line 119, figures 1,4 --	1
A	US 5036165 A (RICHARD K. ELTON ET AL), 30 July 1991 (30.07.91), abstract -- --------	1

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

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Information on patent family members

29/04/98

International application No.

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 1304451 A	20/05/19	NONE	
US 5036165 A	30/07/91	US 5066881 A	19/11/91
		US 5067046 A	19/11/91
		CA 1245270 A	22/11/88
		US 4853565 A	01/08/89